APPLICATION

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TITLE: **DATA ANALYSIS TECHNIQUES FOR DYNAMIC POWER SIMULATION OF A CPU**

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DATA ANALYSIS TECHNIQUES FOR DYNAMIC POWER SIMULATION OF A CPU

Background of Invention

Field of the Invention

[0001] The invention relates to the field of microprocessor design. More particularly, the invention relates to power modeling methodologies for a microprocessor.

Background Art

[0002] With the increased clock frequencies of modern high-performance microprocessors, power usage has increased as well. Consequently, limiting power dissipation has become one of the most stringent design targets. Thus, it is very important to obtain a model providing information to help engineers understand power behavior in a microprocessor. Typically, power behavior is observed by feeding input information into a simulator and then analyzing the results.

[0003] Figure 1 shows a prior art full-chip power modeling simulation in a microprocessor. CPU activity data is generated each cycle (20) and combined with power values per unit of the activity data (22) using power model equations (24). Three values are provided for each unit of activity data (22) corresponding to minimum (MIN), typical (TYP), and maximum (MAX) circuit power conditions. The CPU activity data changes every cycle. CPU activity data (22) may include (1) the number of instructions retired in a current cycle, (2) the number of 1's in a cache line being filled from memory, and/or (3) the number of instructions in stage 3 of the floating point multiplier. The simulator calculates the

power model equation results every cycle and sums them up for equations/sub-blocks to generate full-chip MIN, TYP, and MAX power values (26). After the run, power data is analyzed/summarized (28) by various methods including taking the average over several cycles and the peak variation in power from one cycle to the next. Average power consumption may be used to estimate the sustained temperature that the cooling system must be designed to tolerate. Peak power variation from one cycle to the next can be used to design decoupling capacitors and other circuitry to tolerate changes in inductance.

[0004] Figure 2 shows an example of simulation results generated from a prior art full-chip power modeling simulation. The upper curve represents the worst case maximum value (MAX) at each cycle during a run. The middle curve represents typical power (TYP) for each cycle during the run. The lower curve represents the best case minimum power value (MIN) at each cycle in the run. Power behavior may be categorized in terms of characteristic factors. A factor "Peak" is defined as the highest power point reached over a run. A factor "Low" is defined as the lowest power point reached over a run. A factor "Average" (Avg) is defined as an average over a run. For example, Peak-Min (40) means the highest power point on the Min curve (34). Low-Typ (38) means the lowest power value on the Typ curve (32). Then, Peak-Max (36) means the highest power point on the Max curve (30). The simulation results may be analyzed using various methods. For example, they may be analyzed in terms of Peak, Avg, Low power values, or any other user-defined characteristic factors.

[0005] As the complexity of microprocessors increases, design engineers must deal with massive amounts of information from the results of power modeling simulations. Thus, it is important for the engineers to be able to obtain summary information to get a better understanding of the power behavior of a microprocessor. For example, summary information may provide information to help the engineers design system cooling and charge pumps, and to avoid

resonance frequencies.

Summary of Invention

[0006] In one aspect, a method for analyzing a power modeling simulation comprises receiving a plurality of values of power data from a power modeling simulator, generating summary information relating to single cycle behavior of the power data (where the power data is associated with a specific cycle in the power modeling simulation), analyzing the power modeling simulation using the summary information.

[0007] In another aspect, a method of analyzing power modeling simulation comprises receiving a plurality of values of power data from a power modeling simulator, generating summary information relating to multiple cycle behavior of the power data (where the power data is associated with multiple cycles in the power modeling simulation), and analyzing the power modeling simulation using the summary information.

[0008] In another aspect, a method of data analysis for a power modeling simulation comprises receiving a plurality of values of power data from a power modeling simulator, generating summary information relating to a multi-cycle derivative of the power data (where each power data is associated with at least one cycle in a simulation, and where the multi-cycle derivative is a derivative of at least two particular power data in non-successive cycles), and analyzing the power modeling simulation using the summary information.

[0009] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

Brief Description of Drawings

[0010] Figure 1 shows a prior art power modeling simulation in a microprocessor.

[0011] Figure 2 shows an example of simulation results generated from a prior art power modeling simulation.

[0012] Figure 3 shows analysis processes generating summary information from power simulation data in accordance with an embodiment of the invention.

[0013] Figure 4 shows an example of power simulation results to describe an embodiment of the invention.

[0014] Figure 5 shows an example of a plot using power data presented in Figure 4.

Detailed Description

[0015] The present invention relates to data analysis methods for dynamic power simulation for a microprocessor. In one embodiment, the outputs of a simulator are selectively processed to generate summary information for power behavior of a microprocessor in a run.

[0016] Figure 3 shows a process of generating summary information from power simulation data in accordance with an embodiment of the invention. This embodiment includes three types of summary information: single cycle summary data (50); multi-cycle power (MCP) (52); and multi-cycle derivative (MCD) (54). The resources for these summaries are derived from power simulation data (80).

[0017] To observe rises and falls in power data generated from the simulation during each cycle, single cycle summary data (50) is used. The summary (50) provides the absolute values of Peak and Low, which are derived from the absolute values both within a single cycle and over multiple cycles. In the summary, the Peak and Low absolute values are associated with a specific cycle. The derivative is defined as the difference between two particular associated power values in the simulation.

[0018] In some applications, information from a single cycle may not be enough to accurately reflect the power dissipation. It may take multiple cycles to observe the desired changes in the power dissipation. Thus, in this case, the multi-cycle power (MCP) (52) scheme is used. The MCP (52) scheme provides average values over multiple cycles and reports the peak average value. In this scheme, at every cycle, power data from the current cycle is included with the previous data in a run. Then, the average is calculated. The next average for an N-cycle MCP is obtained by adding in the power for the current cycle, subtracting out the power from N cycles ago, and dividing the total by N to obtain the N-cycle average. The current N-cycle average is compared to the peak seen so far, and if it exceeds the existing peak, the peak is updated to the current N-cycle average. This process is repeated until all of the power data are included. After the process is complete, the peak average is reported. The MCP (52) scheme can be used for any of Min, Typ, or the Max curves. However, the MCP (52) scheme is preferably used for the Max and "TypMax" curves because of practical considerations. For example, the considerations may include observation of power dissipation in a microprocessor. In this case, the Max curve represents the power dissipation at the extreme worst case. The TypMax curve is a hypothetical curve halfway between Typ and Max. It represents the power dissipation at a more realistic worst case.

[0019] Change in power from one cycle to the next does not cover the full range of the change if subsequent cycles continue in the same direction. To collect data showing the full range the power changes, the concept of multi-cycle derivative (MCD) (54) was developed. In this embodiment, a multiple cycle derivative is defined as a group of single cycle power values that progress primarily in one direction. To determine when the direction has changed by a large enough amount to end one MCD and begin the next, various schemes may be applied. For example, an SCD/MCD scheme may be used for the detection of the end of MCD. The scheme uses a method of comparing an SCD/MCD ratio with a threshold

value – a value chosen to accept small changes in the other direction as part of the current MCD while using big changes to terminate the current MCD and begin the next one going the other direction. In the ratio, the numerator represents an absolute value of the SCD. The denominator represents the current MCD value, which is obtained from the difference between the power level at the beginning of the MCD and the current power level. A new MCD starts if the ratio becomes larger than the threshold value. This is an implementation of the MCD (54) scheme derived from single cycle data.

[0020] However, for determining the end of the MCD, it may be difficult for the SCD/MCD scheme to detect accurately the behavior of power data in some special cases. For example, some results may have a "saw-tooth" drop-off behavior, which will be explained with reference to Figure 4. For a more robust method to determine the end point of the MCD, a "retroactive top" scheme is introduced. This scheme uses a method designed to better approximate how human eyes recognize the endpoints of rises and falls in a curve.

[0021] When the retroactive top scheme encounters a positive direction detection of the MCD, and the power data reaches the highest value, that value is recorded. If a new SCD turns in the other direction, which represents a negative value of SCD for the positive direction detection, a "DROP/TOP" ratio is calculated and compared with a threshold value. The "DROP" value is defined as a value calculated by subtracting the current power value from the highest power value. The "TOP" value is defined as a value calculated by subtracting the start power value from the highest power value. In the same manner, for negative direction detection of the MCD, the lowest value is recorded as the bottom value. Then, if a SCD turns in a positive direction, a ratio is calculated. When the ratio reaches a threshold value, the MCD ends at the cycle of the lowest value. Then, the size of the MCD is reported.

[0022] Figure 4 shows an example of power simulation results having saw-tooth drop-off behavior. In this example, the detection process to determine the end of the MCD is explained by using the SCD/MCD scheme and the retroactive top schemes. This exemplary simulation results include the power data (62) presented with SCD (64), SCD/MCD (66), and DROP/TOP (68). The data (62) ranges from cycle 0 to 6 (60). To determine the end of the first MCD using the SCD/MCD scheme, first, the SCD is calculated from the data by subtracting the previous value from the current value. The MCD is calculated by subtracting a start value from the current value. Then, the ratio is calculated. In this example, the ratios are calculated as 2/15 at cycle 2, 2/14, at cycle 4, and 2/13 at cycle 6. These ratios are equivalent to 13%, 14%, and 15%, respectively.

[0023] According to the retroactive top scheme, the top value is recorded as 115. Then, a drop/top ratio is calculated when an SCD turns in the other direction, a negative value in this case. For example, DROP/TOP ratios (68) are calculated to be 2/15 at cycle 2, 3/15 at cycle 4, and 4/15 at cycle 6. These ratios are equivalent to 13%, 20%, and 27%, respectively. Assuming that a threshold value is 15% in this example, the SCD/MCD scheme detects the end of the first MCD at cycle 5 with length 5 cycles and size 13W because the ratio reaches the threshold value at cycle 6.

[0024] According to the retroactive top scheme, when the DROP/TOP ratio reaches a threshold value, the MCD is determined and ends at the top value. Thus, in this example, the ratio reaches 15% between cycle 2 and cycle 4. As a result, the end of the first MCD is reported at cycle 1 with a length of 1 cycle and size 15W. This scheme determines the end of MCD by returning to the top value when forward values are calculated. Figure 5 shows an example of a plot using the power data presented in Figure 4. In this example, the end (70) of the first MCD can be easily recognized.

[0025] After all MCDs are obtained using the MCD scheme, the MCDs may be grouped using an exponential binning approach to obtain information on the MCDs depending on the length of the MCD in cycles. In this approach, the index of the length increases exponentially. That is, the index is doubled starting at 1. Thus, the MCDs are grouped in lengths of 1, 2, 4, 8, 16, 32, 64, etc. The grouped MCDs may be summarized by using a histogram. In this case, for each group, the total number of the grouped MCDs is reported and the peak MCD is also reported with information of the size and the number of cycles.

[0026] The results derived from the schemes are gathered into a resulting file. The file is reported as summary information for power behavior of a microprocessor in the run. The file may be stored in a database or any other storage mechanism to help engineers design system cooling and charge pumps, and avoid resonance frequencies. Additionally, such information may help design a microprocessor with a minimum number and variety of charge pumps that cover major widths and lengths of power derivatives.

[0027] Generating summary information for power data is achieved by selectively processing power information generated from a power modeling simulation. However, alternative schemes or summaries may also be added to analyze the power information.

[0028] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.